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CELLULAR NETWORK CAPACITY PLANNING USING THE COMBINATION ALGORITHM FOR TOTAL OPTIMISATION

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Abstract – The Combination Algorithm for Total Optimisation (CAT) is proposed to support smooth upgrading of third generation systems and to fulfil the requirements of current cellular networks. The CAT algorithm solves the problem of base-station location in different environments. Until now experiments were based on simple statistical propagation models such as Okumura-Hata. In this paper new results based on the use of a more complex ray-tracing approach combined with inhomogeneous capacity requirements are presented and discussed. Example results are given for various capacity and coverage targets.

I. INTRODUCTION

The introduction of third generation mobile networks will provide customers with a growing number of multimedia services. To support the seamless upgrading of current cellular networks, and to fulfil the requirements of third generation systems, new planning tools are required to meet the complexity of the resource dimensioning. The expected costs and benefits of these new networks will heavily depend on the capabilities of the new planning tools.

Planning tools affect the infrastructure cost and planning complexity of a cellular network [1]. The search for an optimisation tool that can solve the base-station location problem is not new, in recent years many authors have investigated the application of different algorithms to solve this problem [2,3,4]. In this paper attention is given to the development of the CAT algorithm based on the introduction of two new modules that affect the way the algorithm operates and consequently the results it produces.

Until now the operation of the CAT algorithm was based on the use of the Okumura-Hata model and homogeneous traffic distribution assumptions [5]. In this paper two new modules are introduced into the CAT algorithm. The old propagation module is replaced by a powerful three-dimensional deterministic model (see section IV) and the capacity module has been upgraded to consider inhomogeneous traffic distributions throughout the planning area (section V).

II. PROBLEM DESCRIPTION

The fundamental idea behind the base-station placement problem is to find a *minimum* number of base-stations that meet the operator's requirements over a given area. The exact number of requirements will vary depending on the operator's network. In this paper the requirements are based on meeting user supplied capacity and coverage targets. A number of assumptions are made to solve the problem efficiently and these are presented below.

The planning area is described as the universal set, U, that contains all points in the area. A number of discrete user supplied points or *control nodes* are used to represent the capacity and coverage requirements in the area. This set is mathematically denoted by $CN_{c,n}$ and is defined in equation 1, where c represents the location of each control node (x, y) and n the total number of such nodes.

$$CN_{c,n} = \{c_i : i = 1 : n, c_i \in U\} \quad (1)$$

The number and location of base-stations are user supplied and represented by the $BS_{b,s}$ set. $BS_{b,s}$ represents an over specified set of base-station locations and is defined in equation 2, where b represents their location (x, y) and s the total number in the study area.

$$BS_{b,s} = \{b_j : j = 1 : s, b_j \in U\} \quad (2)$$

The specification for user supplied base-station locations is used as a matter of practicality, due to the fact that network operators cannot locate base-stations in arbitrary locations, such as protected buildings, difficult geographical locations and so on. The use of fixed base-station locations avoids this problem and assure a sensible solution to the base-station placement problem.

For a given number of control nodes and base-stations an optimisation algorithm must deploy a minimum number of base-stations to satisfy the operator's overall requirements. These requirements are defined in U in the form of control nodes and are based on capacity and coverage. Two external modules provide the algorithm with the necessary information on which optimisation is

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based. Coverage is provided in the form of power information generated using a 3-D propagation model [6]. Capacity calculations are based on standard inhomogeneous traffic distributions [7].

Every control node defined in the $CN_{c,n}$ set must meet the planning requirements, R_n defined by the user in equation 3.

$$R_n = \{P_{\min}, C_{\max}\} \qquad (3)$$

Where P_{min} represents the minimum power (dBm) target for each control node and C_{max} represents the maximum capacity in the area. While the target value of P_{min} remains constant for each control node, the value of C_{max} may vary depending on the traffic demands in each area (for inhomogeneous traffic distributions).

Figure 1 shows a typical area, U, in which a number of control nodes have been distributed in areas that need to satisfy certain capacity and coverage constraints. For inhomogeneous traffic distributions, areas with different traffic demands must be specified (denoted by white fine lines in figure 1). The sub-areas have traffic demands associated with them, C_{max}, this value determines the capacity value assigned to each control nodes in that area (see section V)

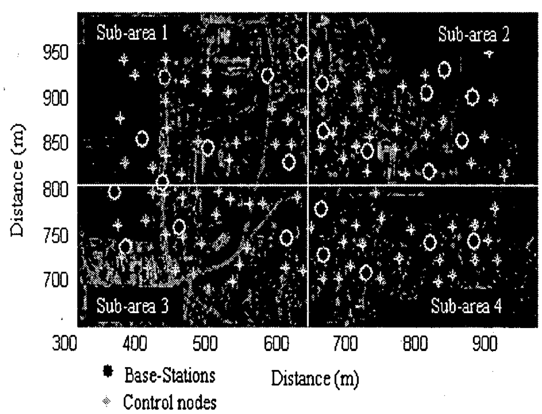

Figure1. Typical microcell scenario

III. THE CAT ALGORITHM

The CAT algorithm is based on a combinatorial approach. The basic idea relies on analysing all possible base-stations in the $BS_{b,s}$ set. The optimum combination is the subset with the highest metric (i.e. the greatest number of adequately supported control nodes). In general, the number of supported control node increases with the number of deployed base-stations.

The CAT algorithm is used to find a minimum subset, *BSM*, from the over specified set $BS_{b,s}$, (see equation 2). This subset must contain all the elements of $CN_{c,n}$, and must fulfil the planning requirements defined in equation 3.

$$BSM \subset BS_{b,s} \quad (4)$$

The power (dBm) and capacity (Erlangs) values at each control node must meet the respective user defined P_{min}, and C_{max} targets.

The fundamental theory of the CAT algorithm is based on equation 5.

$$sC_r = \sum_{r=1}^{r=s} \frac{{}_sP_r}{r!} = \sum_{r=1}^{r=s} \frac{s!}{(s-r)!r!} = \begin{pmatrix} s \\ r \end{pmatrix} \qquad (5)$$

Where s denotes the total number of base-stations in the $BS_{b,s}$ set, r the number of elements taken without repetition, sP_r, the number of permutations of given a number of base-stations taken r at a time, and ${}_sC_r$, the number of combinations of given s, taken r at a time.

Although a solution can be found by implementing equation 5, the computation time grows exponentially with the number of possible base-stations, s [5]. This makes the direct use of equation 5 impractical. For this reason, the CAT algorithm uses complex selection and merging processes to reduce the computation time and enable the calculation of a minimum solution [5].

The number of possible solutions offered by the CAT algorithm is generally much greater than one. This condition allows the user to introduce tighter bounds or restrictions to find the best possible solution between the groups containing the same number of elements or base-stations. For example, it is possible to select the base-stations that provide more equally distributed coverage to the control nodes. This means that the CAT algorithm offers the best possible solutions according to the user's need and not just the first solution found, which is the case for other algorithms trying to solve the base-station placement problem. The speed and complexity of the CAT algorithm is a function of the total number of possible base-stations.

IV. THE COVERAGE MODULE

The coverage module is based on a powerful three-dimensional model that can predict propagation in macrocells [8] (using radar cross-section modelling) and microcells [6] (using classical vector based ray tracing). The coverage and interference effects are modelled using these models.

In the studies presented in this paper, emphasis has been placed on microcellular scenarios, where the need to deploy large numbers of base-stations is greatest.

The ray-tracing model operates using three-dimensional vector mathematics and factors such as polarisation and angle of arrival are fully incorporated. The model predicts power, time dispersion, coherence bandwidth and spatial multipath. Figure 1 shows the point to point power prediction for 40 base-stations and 180 control nodes (the transmitted power is normalised to 0 dBm).

As can be seen in figure 2, the power for a given control node varies depending on the base-station chosen for coverage. The shape of the profile is clearly irregular, and shows the difficulties of covering all the control nodes using a small number of base-stations.

The CAT algorithm interacts with the coverage module to analyse the links between potential base-stations and control nodes. From this, it is possible to obtain a matrix with the value of power in every control node for every base-station serving the area. This power value is defined as Pij , which is the value of power in control node i for each base-station j serving the area and for the final solution must meet the user $P_{min.}$ target.

$$\forall i \Rightarrow Pc_i >= P_{\min} \qquad (6)$$

Where $Pc_i = max\ Pij$ for the all j base stations in BSM.

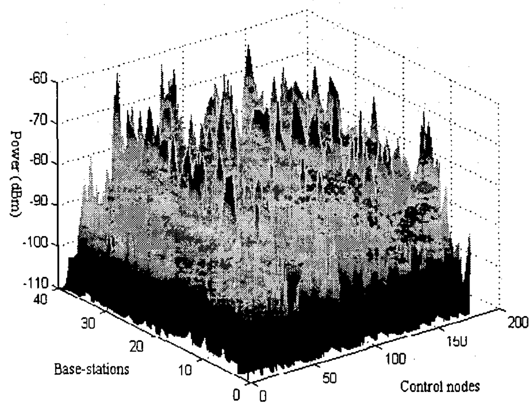

Figure 2. Base-station to control node power prediction matrix

V. THE CAPACITY MODULE

The CAT algorithm also interacts with a capacity module to calculate the traffic distribution and the traffic load for each cell.

The capacity model considers the inhomogeneous traffic distribution throughout the planning area. The traffic density (Te) in an area is commonly defined on a two-dimensional area grid, (in Erlangs per square Km.)[7]. This information is user-provided to the CAT algorithm and can be determined either through network measurements or via statistical methods. For the first case, the network is dimensioned to offer a minimum quality of service (e.g. blocking probability, B) during the busy hour. The busy hour is defined as the hour exhibiting the largest average traffic [7]

Traffic density can also be obtained through the analysis of morphological information. The morphological information includes building density, the size of cities, customer penetration and subscriber behaviour (e.g., residential or business users,...etc). Through this type of statistical analysis it is possible to estimate the number of potential users in an area.

In real networks the traffic distribution throughout the planning area is inhomogeneous, however, certain characteristics are shared within small distances or grid areas. Based on this traffic information, different areas with different traffic distributions are identified and included in our model.

In the study presented in this paper, the number of Erlangs per area is user defined. The fact that the data is based on a statistical approach or on real network measurements would obviously influence the final results as the traffic load predictions can differ considerably. However, the CAT algorithm efficiency and modus operandus will be unaffected.

For every sub-area a specific number of Erlangs is defined. The traffic demand for a particular control node is the linear portion of the total traffic in the sub-area (i.e. the sub-area traffic divided by the number of control nodes in the area). After this calculation every control node will have a traffic value Cc_i, associated to it. The sum of all the individual control node traffic demands will give the total traffic demand for the sub-area.

The number of base-stations necessary in each sub-area depends on the capacity target levels, C_{max} To calculate this value a suitable quality of service must be defined. The blocking probabilities for handover and initial access calls can be used to describe the corresponding QoS [9].

The CAT algorithm currently makes use of the Erlang-B formula. The Erlang-B formula relates the average channel occupancy (in Erlangs), the number of channels (an integer) and the blocking probability, under the assumption that the instants of call establishments and the duration of calls follow Poison processes [9]. That is:

$$E_B(Te, N) = B \qquad (7)$$

The traffic in the different sub-areas and the desired blocking probability are passed to the CAT algorithm. With this information, and by making use of the Erlang-B formula, the number of channels, N, required in each base-station and consequently the number of base-stations in each sub-area can be calculated.

VI. CASE STUDY

A case study is presented in this section, the results and conclusions for the propagation and optimisation study are presented for a microcellular study centred around the town of Malvern in the U.K.

The propagation and capacity modules described in the previous sections have been used for this case study, however these modules are not a limitation and the use of a module based on a different approach could easily be incorporated into the CAT algorithm. The results presented here are based on power predictions and inhomogeneous traffic requirements for the different areas. Although the power predictions only need to be calculated once for each study through the experiment, different traffic requirements can be introduced in the sub-areas to produce solution, depending on expected traffic loads.

Figure 1 shows a typical microcell scenario with the number of possible base-stations or elements in $BS_{b,s}$, set to 24. The number of control nodes is set to 93. The location of possible base-stations is based on locations where deployment would be possible, the control nodes are evenly dispersed throughout the area.

The area is divided into four sectors, each containing a unique traffic requirement, figure 1 shows the different sub-areas. Although the shapes here are rectangular and occupy similar sizes, this can be modified and the areas can adopt different sizes and shapes to satisfy traffic requirements.

The non-uniform traffic information present in each individual sub-area is used to set the *Cci* parameters for each control node. The study was performed at 1.8 GHz assuming omni-directional antennas and a base-station transmit power of 100 mW. All control nodes in the area were configured with P_{min} at -70 dBm (the study is based on GSM assuming fade and building penetration margins).

Three different scenarios are considered in this study. For the first, a low homogeneous capacity level has been considered throughout the area of study, so the solution will essentially be based on coverage. A minimum number of base-stations is selected by the CAT algorithm to cover the area based on power predictions.

Figure 3 shows one of the possible solutions to the problem. Given that the main constraint is only based on power (since the capacity requirement is low), a number of solutions are suggested by the CAT algorithm to satisfy the requirement. The solution shown in figure 4, contains a total number of 8 base-stations that provide 100% coverage for all the control nodes in addition to meeting the capacity requirements in the area.

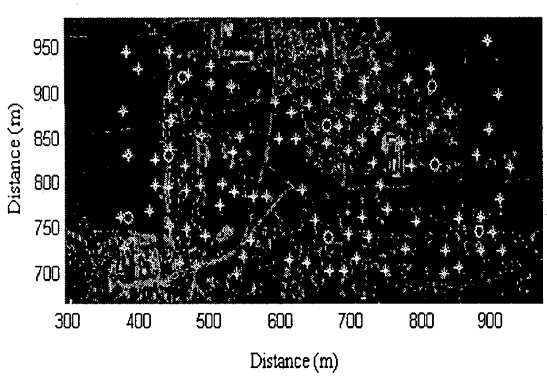

Figure 3. Solution for 100% coverage and low homogeneous traffic distribution

Given that the traffic requirement is homogeneous it can also be observed that the location of the base-stations is also relatively homogeneous. The power transmitted by each base-station is assumed to be the same. Due to the fact that the traffic requirement for this case is low, by increasing the power in certain base-stations it is possible to reduce the number of base-stations necessary and still satisfy the coverage in the area.

For these types of scenario the algorithm shows the user the imbalance between capacity and coverage in the proposed solution, and recommends the user to consider a higher transmitted power in the base-stations. The final solution will depend on the capacity targets and the system's maximum transmit power level. Figure 4 shows a new solution that contains 6 base-stations. The number of base-station here has been imposed due to traffic restrictions.

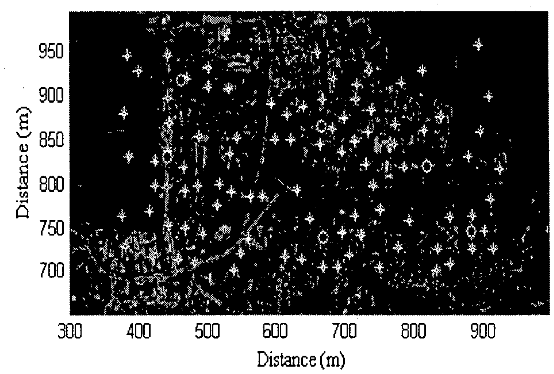

Figure 4. Reduction of base-stations by increasing the power transmitted

The second study considers an inhomogeneous traffic distribution, that is, each sub area in figure 1 has associated a different number of Erlangs. The number of Erlangs per sub-area assumed in this scenario (figure 5) is shown in table 1.

	Sub-area 1	Sub-area 2	Sub-area 3	Sub-area 4
Figure 5	85 E	125 E	80 E	40 E
Figure 6	110 E	170 E	80 E	72 E

Table 1. Traffic capacities per sub-area

The blocking probability is set at 2%, a typically acceptable value [10]. The number of carriers assigned to the base-station ranges from 1 to 7 according to the traffic. Note that the number of carriers is directly determined by the traffic and does not need to be optimised [10]. Table 2 shows the typical values of Erlangs for a 2% blocking probability and the corresponding number of carriers and voice channels, (GSM is assumed). Note that the choice of blocking probability will change the voice channel requirement.

Carriers	1	2	3	4	5	6	7
Erlang	2.9	8.2	15	22	28	36	43
Voice Channels	7	14	22	30	37	45	53

Table 2. Number of transmitters per traffic capacities and channels

Although the solution that the CAT algorithm selects for these conditions differs from the previous solution, the number of necessary base-stations remains unchanged. This means that there are sufficient numbers of base-station to satisfy the new traffic requirements and the solution is balanced. This scenario is shown in figure 5.

For a scenario in which the number of Erlangs increases in certain sub-areas, the CAT algorithm offers a new solution that satisfies the traffic requirements. This case can be seen in figure 6, where the number of Erlangs per sub-area is shown in table 1.

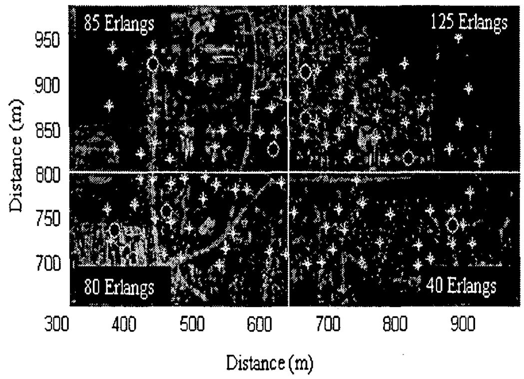

Figure 5. Solution for 100% coverage and inhomogeneous traffic distribution

The operator's necessities have now changed and this means that the traffic requirements in some areas are different relative to the previous example. To satisfy the new conditions the CAT algorithm must change the solution and increase the number of base-stations needed to eleven.

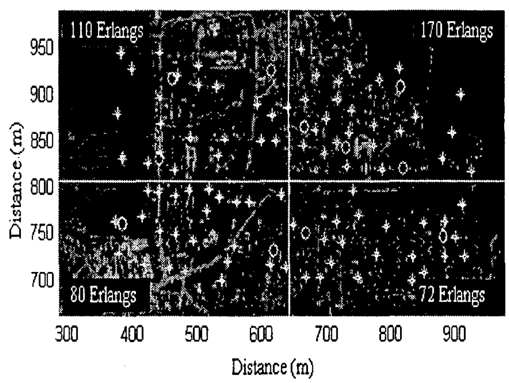

Figure 6. Increasing traffic demand

In the last two cases it is possible to see how the algorithm chooses different configurations for different traffic requirements, however some of the base-stations from configuration 5 remain the same as those used in the solution presented in figure 6.

So far the emphasis has been placed on unplanned areas (green field sites). A scenario that has not been mentioned so far is the re-planning of existing networks. For deployed areas that need a number of extra-services, such as more capacity, extended coverage, etc. For this type of scenario, the fixed base-stations that cannot be removed or altered are introduced into the CAT and deployment of such base-stations is considered compulsory.

VII. CONCLUSION

Cost-efficient planning and deployment of a cellular network should always pursue the strategy of providing sufficient traffic capacity and radio coverage throughout the deployment area. The CAT algorithm provides the flexibility to locate a minimum number of base-stations in a certain area and to satisfy a number of user-supplied conditions. The use of good propagation and capacity modules enhances the efficiency of the algorithm and alters the results, however the modus operandus of the CAT algorithm remains unaltered.

In this paper results were presented for inhomogeneous traffic requirements. Non-uniform traffic distribution is indisputable in real networks, the location of base-stations varies with the traffic requirements in the different sub-areas, and not homogeneously throughout the totality of the area of study, therefore a base-station planning algorithm should be able to provide this necessity.

The CAT algorithm is a non-iterative algorithm that optimises the capacity and location of each base-station accordingly to the user requirements, providing quality solutions in a number of environments.

VIII. ACKNOLEGMENTS

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